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THE NLC INJECTOR SYSTEM*

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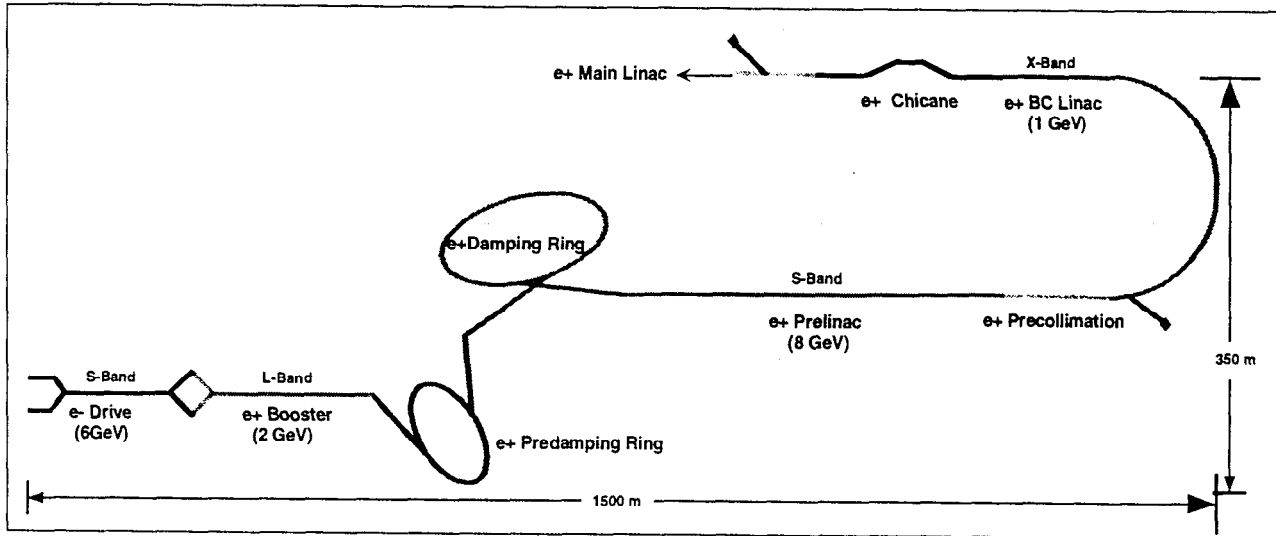


Figure 1: Layout of the NLC Positron Injector System.

Abstract

The Next Linear Collider (NLC) Injector System is designed to produce low emittance, 10 GeV electron and positron beams at 120 hertz for injection into the NLC main linacs. Each beam consists of a train of 95 bunches spaced by 2.8 ns; each bunch has a population of 1.15×10^{10} particles. At injection into the main linacs, the horizontal and vertical emittances are specified to be $\gamma\epsilon_x = 3 \times 10^{-6}$ m-rad and $\gamma\epsilon_y = 3 \times 10^{-8}$ m-rad and the bunch length is 100 μ m. Electron polarization of greater than 80% is required. Electron and positron beams are generated in separate accelerator complexes each of which contain the source, damping ring systems, L-band, S-band, and X-band linacs, bunch length compressors, and collimation regions. The need for low technical risk, reliable injector subsystems is a major consideration in the design effort. This paper presents an overview of the NLC injector systems.

1 INTRODUCTION

In the NLC [1] Injector System, the electron and positron beams are generated in separate accelerator complexes

located at the entrances to the two main linacs, separated by about 32 km. Each injector complex consists of a source system, a damping ring complex, and a prelinac and bunch length compression system. A schematic layout of the positron injector systems is shown in Figure 1. In the electron injector (not shown), redundant electron sources feed the e- Booster which is coupled directly to the e- Damping Ring (there is no e- Predamping Ring). Table 1 lists the beam parameters at injection to the main linacs.

Table 1: NLC Injector System Beam Parameters

Energy	E	10 GeV
Energy Spread	$\Delta E/E$	1%
Single Bunch σ_E	σ_E/E	1.5%
Horizontal Emittance	$\gamma\epsilon_x$	3×10^{-6} m-rad
Vertical Emittance	$\gamma\epsilon_y$	3×10^{-8} m-rad
Bunch Length	σ_z	100 μ m
Electron Polarization	P_e	>80%
Positron Polarization	P_p	No
Particles/Bunch	n_b	1.15×10^{10}
Number of Bunches	N_b	95 bunches
Bunch Spacing	T_b	2.8 ns
Repetition Rate	f	120 Hz

In the electron injector, polarized electrons are produced using a III-V semiconductor photocathode, accelerated to 1.98 GeV in an S-band linac and injected into a damping ring. Upon extraction from the damping ring, the bunch length is compressed and the beams are accelerated to 10 GeV in an S-band linac. Initial transverse collimation is

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done prior to transport through a 180° turn-around. Second stage bunch length compression is accomplished using a 1 GeV X-band linac followed by a dipole chicane. An optical matching section and diagnostic region follow the compressor chicane. Tune-up dumps permit full beam preparation prior to injection into the 180° turn-around and into the main linac.

On the positron side, electrons are produced using a thermionic cathode and accelerated to an energy of 6.22 GeV in an S-band linac before impacting a target to produce positrons. Initial capture and acceleration of positrons to the damping ring energy of 1.98 GeV is done in an L-band linac system. Redundant e- and e+ sources are incorporated into the design to enhance availability. The large positron emittances are initially damped in a predamping ring prior to injection into the damping ring. The positron damping ring and subsequent accelerator systems are identical to those on the electron side with the notable exception that polarization spin manipulation solenoids and polarimeter are omitted. The positron beamlines allow for installation of spin preserving solenoids should the NLC be configured for electron-electron collisions.

The NLC emittance budget allows for dilution of the beam emittances by 20% in the horizontal and 50% in the vertical between extraction from the damping rings and injection into the main linacs. This budget is used to calculate tolerances. The values of $\gamma\epsilon_x = 3 \times 10^{-6}$ m-rad and $\gamma\epsilon_y = 3 \times 10^{-8}$ m-rad are the undiluted design emittances at extraction from the damping rings.

2 ELECTRON PRODUCTION

Polarized electrons are produced using a conventional dc gun and III-V semiconductor photocathode. Electron polarization of greater than 80% is required. The design has a 714 MHz, 2 cavity subharmonic bunching system to allow for a luminosity upgrade to 1.4 ns bunch spacing. The population of individual bunches is a relatively modest 2×10^{10} e-/bunch from the gun. This single bunch intensity target has been achieved in routine SLC operations with 80% polarization. The requirement of 95 successive bunches per beam pulse presents a significant challenge for initial electron production from the cathode due to the charge limit phenomenon [2]. R&D directed towards an NLC cathode capable of producing the requisite charge and polarization is ongoing at SLAC and Nagoya University. Care is also taken in the design of the bunching and linac systems to compensate for the long range longitudinal wakefield effects on the 95 bunch train.

3 POSITRON PRODUCTION

Positrons are produced by targeting a 6.22 GeV electron beam into an SLC style positron production system consisting of a water-cooled, 4 r.l. W-Re target followed by a 5.8 T magnetic flux concentrator, a 1.2 T tapered field solenoid, and a 0.5 T uniform field solenoid. L-band

accelerator sections are used in the initial capture region to accelerate the beams to 250 MeV. After separation and removal of the electrons, the positrons are accelerated to the predamping ring energy of 1.98 GeV in an L-band linac. A yield of 2 positrons per electron into a phase space edge acceptance of 0.06 m-rad is expected. This yield normalized by the incident electron energy is a factor of 4 improvement over the SLC [3]. L-band (1428 MHz) has been chosen because of the large transverse aperture and longitudinal acceptance which are fully utilized in defining the acceptance and subsequent yield calculations. Energy loading in the initial capture regions is compensated using a ΔF correction scheme. ΔT compensation is employed in the rest of the L-band linac [4].

The 1998 failure of the SLC target has caused significant concern regarding the viability of the NLC positron system design which is based on the SLC system. The concern is whether the SLC system failed in an acute manner from exceeding the target damage threshold or from accumulated stress on the target. The former requires a significant redesign of the NLC positron systems whereas the latter means that the design is viable albeit the targets will age and require preemptive replacement. Analysis of the SLC target failure is being undertaken in collaboration with LLNL and LANL. This analysis is expected to be completed during the summer of 1999.

4 DAMPING RINGS

The vertical emittance of the beams is reduced by a factor of 3000 in the damping rings. The rings operate at 1.98 GeV and the design output emittances are $\gamma\epsilon_x = 3 \times 10^{-6}$ m-rad and $\gamma\epsilon_y = 3 \times 10^{-8}$ m-rad. The transverse damping time is 5.2 ms. Damping occurs dominantly from radiation produced in a 50 m wiggler section. Beams are damped in the rings for 25 ms (three inter-pulse periods); at any one time there are three pulse trains in each ring; the circumference of the rings is 300 m. A 1 MW, 714 MHz rf system generates gap voltages of 1.5 MV utilizing 3 PEP-II style damped, rf cavities [5]; the bunch length at extraction is $\sigma_z = 4$ mm. The rings are designed to operate at a maximum intensity of 1.6×10^{10} particles per bunch whereas the nominal operating intensity is about 1.2×10^{10} .

A predamping ring reduces the initial positron rms emittances from $\gamma\epsilon_{x/y} = 0.04$ m-rad down to $\gamma\epsilon_{x/y} = 100 \times 10^{-6}$ m-rad for injection into the positron main damping ring. Beams are predamped for 16.6 ms; there are two pulse trains in the system at any time; the circumference of the predamping ring is 210 m [6].

5 INJECTOR LINACS

Seven rf linacs, six capture regions, and four compressor sections are required in the NLC Injector System. These linacs are based on L-band, S-band, and X-band rf systems. S-band linacs are used for the initial

acceleration of electrons on both the electron and positron side, for energy compression of electrons prior to injection into the damping ring, and for acceleration from 1.98 GeV to 10 GeV after the damping rings on both sides. L-band linacs are used for the initial positron capture and acceleration to 1.98 GeV. L-band rf sections are also employed for energy compression of positrons prior to injection into the predamping ring and for the first stage of bunch length compression of both electrons and positrons. The linacs used for the second stage bunch length compression are based on the X-band technology being developed for the NLC main linacs. The beam loaded gradients in the L-band and S-band linacs have been chosen to be 13 MV/m (15 MV/m) and 17 MV/m (21 MV/m unloaded), respectively [7]. The operating gradient at X-band is 46 MV/m loaded (66 MV/m unloaded).

The standard L-band rf module consists of a single klystron feeding a single SLED system which in turn powers three 5 m long accelerator sections. A standard S-band rf module has a single klystron powering a single SLED system with the outputs of two SLEDs combined to power six 4 m long accelerator sections (each klystron effectively feeds 3 accelerator sections). A standard NLC X-band klystron 8-pack powers twelve 1.8 m accelerator structures.

Both the L-band and S-band systems use double iris, side-wall coupled KEK style SLED-I rf compression systems [8]. The L-band SLED systems are scaled versions of the S-band SLEDs with modification to the coupling β for performance optimization. A single klystron feeds a SLED system. The outputs of the S-band SLEDs are combined and distributed to the accelerator sections. The combination of the SLEDs permits vernier control of the rf waveform for beam loading compensation while allowing for constant power delivery to the structures in the event that beam pulses are suppressed or shortened during a machine protection system fault and recovery. At X-band, a modified DLDS is used for rf pulse compression. Modification is required because the distance between the triplets of sections is reduced in the Injector System design with respect to the layout in the NLC main linacs. The DLDS is doubled in length and folded back upon itself.

The output of the S-band klystron is 65 MW for 5 μ s. It is essentially an improved version of the SLAC 5045 tube. L-band klystrons of 75 MW, 6 μ s should be achievable with existing technology. The X-band tubes are standard NLC 75 MW, 1.5 μ s devices.

In total, the NLC Injector System design has 441 accelerator sections powered by 157 klystrons and 136 SLEDs at S-band, 44 accelerator sections powered by 23 klystrons and 14 SLEDs at L-band, and 24 accelerator sections powered by 16 klystrons and 2 DLDSs. All of this hardware needs to be developed.

6 BUNCH LENGTH COMPRESSION

The bunch length of the extracted damping ring beam is reduced in 2 stages. An 80 MeV section of L-band linac and a 10-dipole wiggler reduces σ_z from 4 mm to 500 μ m prior to injection into the prelinac. After acceleration to 10 GeV and precollimation, transport through a 314 m long 180° turn-around, a 1 GeV X-band linac, and a 32-magnet dipole chicane reduces σ_z from 500 μ m to 100 μ m for injection into the main linacs. Three bunch length diagnostic stations provide tune-up and monitoring capability. Each σ_z station contains an optical port for streak camera measurements and an rf cavity for parasitic monitoring. For $\sigma_z = 100 \mu$ m, streak camera resolution may not be adequate in which case Fourier spectroscopy techniques will be used. As a backup, the first diagnostic station in the main linac can be used as a bunch length monitor using a standard cross-phasing technique.

7 SPIN SYSTEM AND PRECOLLIMATION

Superconducting solenoids are used in conjunction with the bending in the damping ring transport lines to rotate the electron spin into the vertical for damping and then into arbitrary orientation for injection into the prelinac system. After the damping ring, the asymmetry in beam emittances dictates that the solenoids be split and separated by an optical transformation of +I in X and -I in Y to prevent vertical emittance dilution due to coupling. A Compton polarimeter located at injection to the main linac utilizes a laser wire IP, polarized laser light, and the second tune-up dumper. Polarization measurements require dedicated beam time.

Initial collimation of transverse beam halo and tails occurs prior to transport through the 180° turn-around of the second bunch length compressor. Collimation is done using a set of 8 horizontal and 4 vertical, adjustable jaw pairs. Additional cleanup of the debris generated by the collimation takes place downstream in the high dispersion regions of the 180° turn-around.

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